U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Fuel Cycle R & D Program Separations and Waste Form Research and Development

Terry A. Todd, PhD

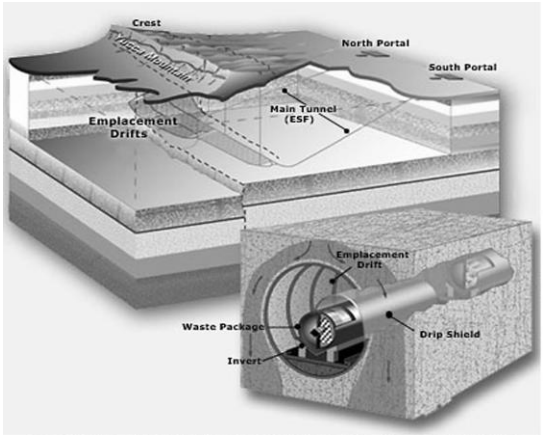
Idaho National Laboratory

Blue Ribbon Commission, Reactor and Fuel Cycle Technologies Subcommittee

July 12, 2010

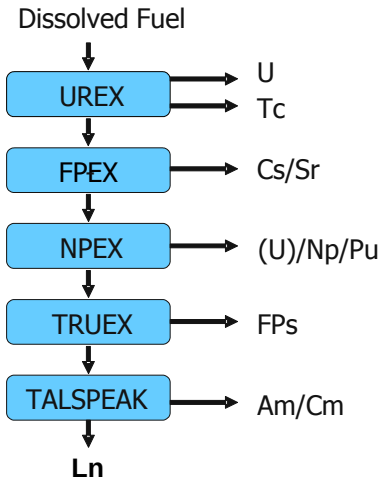
Background

- **The Advanced Fuel Cycle Initiative (AFCI) began in FY-03, but was preceded by AAA and ATW programs**
  - **Development and demonstration program for closing the nuclear fuel cycle**
  - **Focused on enhanced performance of Yucca Mt. repository**
    - **Separation of short-term and long-term heat generating radioisotopes from fuel**
    - **Laboratory-scale demonstrations of UREX+ and pyroprocessing separation technologies**
- **GNEP was introduced in 2006 and was focused on near-term implementation of fast reactors and used fuel reprocessing**



Aqueous Processing Background

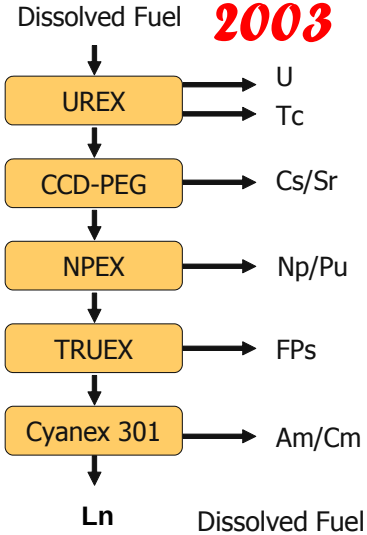
- **The UREX (uranium extraction) process was developed and demonstrated under AFCI to separate only uranium from nuclear fuel, leaving plutonium with the remaining fuel components (UREX is a modification of PUREX)**
  - Follow on processes to remove fission products and manage transuranic elements were also added on to the UREX process. This was designated as **UREX+**
  - Several laboratory-scale demonstrations (~0.5 to 1 kg of used fuel) were completed for various UREX+ flowsheets
  - Process feasibility was demonstrated
  - Follow on studies indicated that the UREX+ options were very complex (would be difficult to remotely-operate at large-scale) and would be prohibitively costly
  - Industry proposed similar PUREX-based processes for U/Pu/Np recovery (COEX, NUEX) under GNEP
    - *UREX, COEX, etc, offer advancements over PUREX, but limited improvement in resource utilization and waste management*

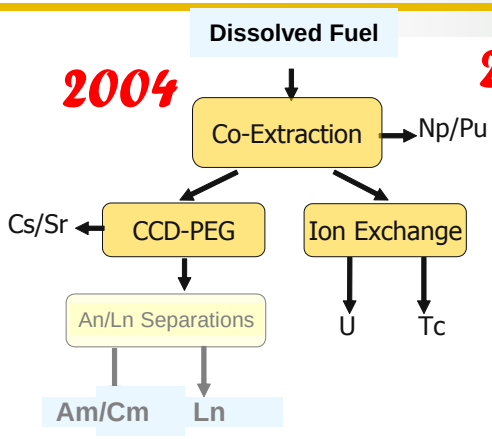


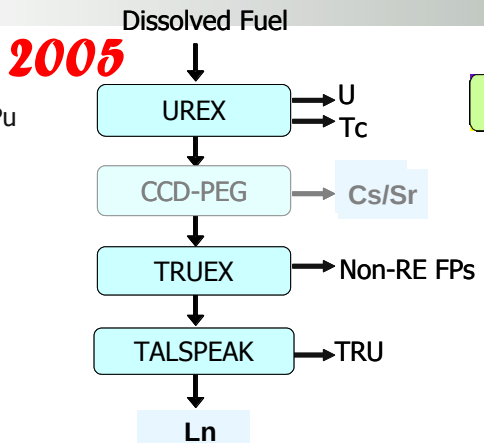
U.S. DEPARTMENT OF ENERGY

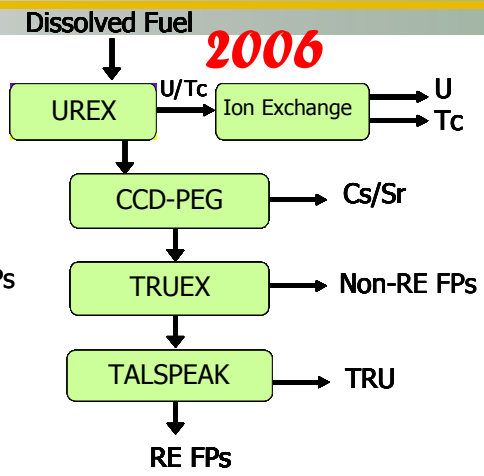
Nuclear Energy

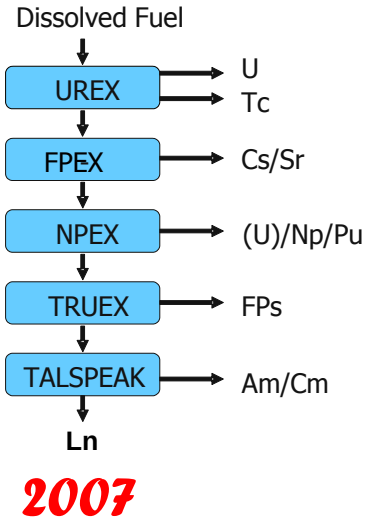
Lab-scale demonstrations with used nuclear fuel (aqueous)

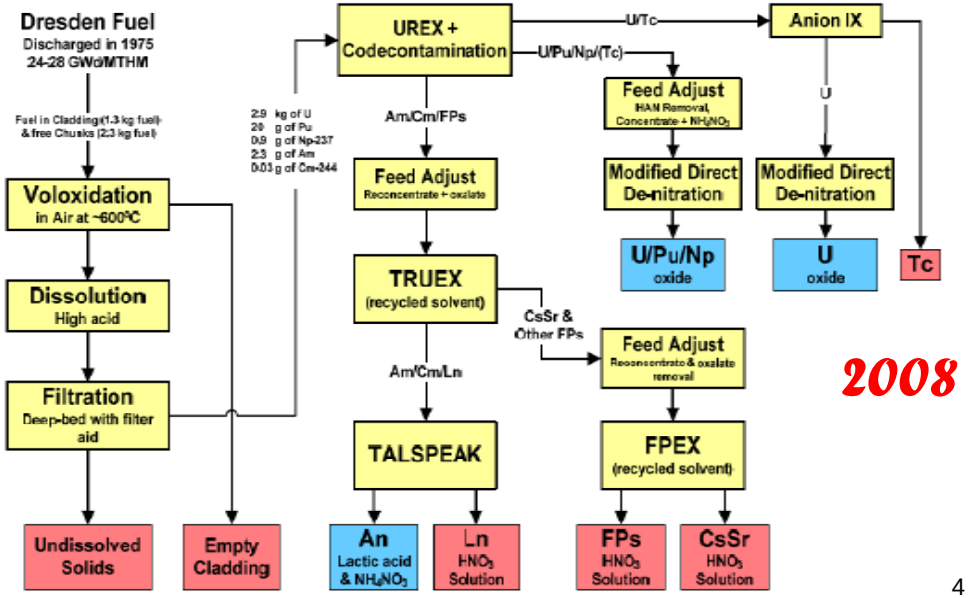










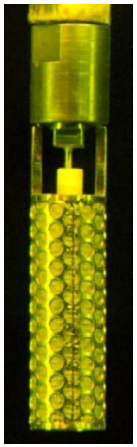


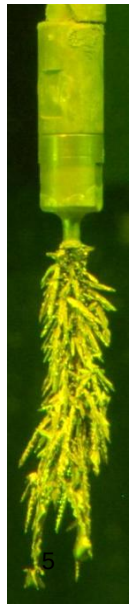
U.S. DEPARTMENT OF ENERGY

Nuclear Energy

Pyrochemical Processing Background

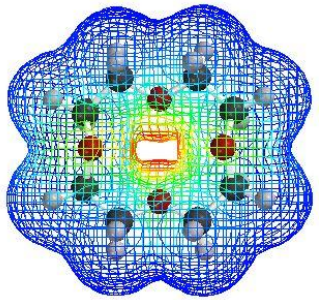
- **Pyrochemical processing was developed to recycle metal fast reactor fuel under the Integral Fast Reactor (IFR) program**
- **Currently being used to treat sodium-bonded Experimental Breeder Reactor (EBR-II) metal fuel for disposal at INL**
  - Separate sodium from fuel and recover uranium (driver fuel is Highly Enriched Uranium (HEU))
  - Engineering –scale operation since 1995
- **Electroreduction of oxide fuels has been demonstrated at the laboratory-scale, as a head-end to the pyroprocess**
- **Industry proposed a pyrochemical recycle approach under GNEP**
- **A few key steps of the process still need to be fully demonstrated, e.g.**
  - TRU recovery and purity
  - Separation of TRU and fission products from salt to enable recycle/disposal

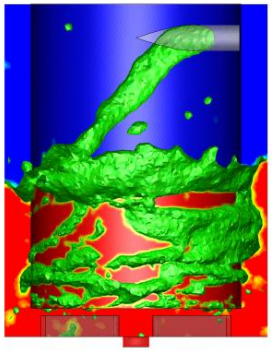


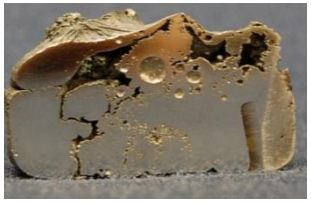


Fuel Cycle R&D Program

- **In 2009, the GNEP program was changed to the Fuel Cycle R&D program**
  - **Program emphasis changed from near-term implementation to goal-oriented, science-based research with longer-term focus**
  - **Prior focus on lab-scale demonstration redirected to understanding fundamental science of separation methods via coupled theory, experimentation and modeling**
  - **Emphasis on science will focus R&D, provide better outcomes and reduce the overall cost of development**
  - **Waste form and Separations programs combined – similar science-based focus with generic repository**
  - **Dual path R&D approach**
    - **Evolutionary and revolutionary R&D**

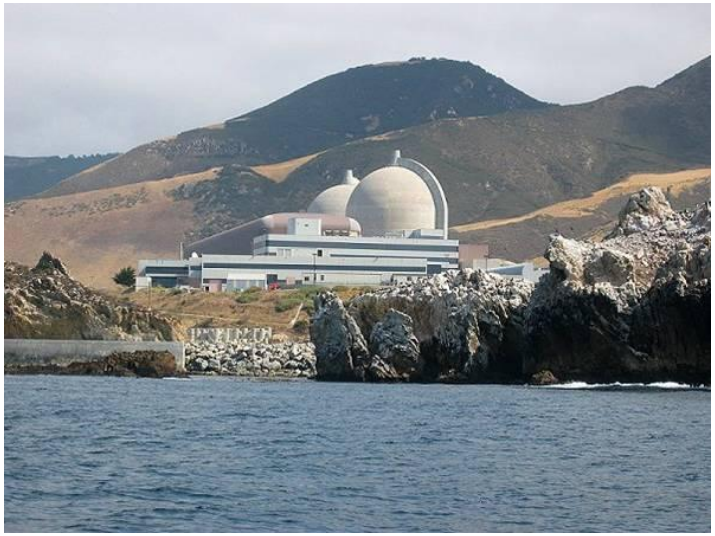






Separations and Waste Forms Objective

- **Develop the next generation of fuel cycle separation and waste management technologies that enable a sustainable fuel cycle, with minimal processing, waste generation and potential for material diversion**
  - Our job is to develop viable and economic technical options that will inform future decisions on the nuclear fuel cycle



Separations and Waste Forms Grand Challenges –

Grand Challenges

- Single-step separation process for americium or transuranic elements (TRU)
- Near-zero radioactive off-gas emissions (an order of magnitude lower than risk-based regulations)
- Reduce waste volume (generation) for high-level , low level, and greater than class C wastes, by an order of magnitude
- Increase durability of high-level and low level wastes by an order of magnitude over current reference (glass)

Addressing Grand Challenges

- To address some of the most difficult challenges in the separations and waste forms area, we formed two "Sigma Teams"
  - Multidisciplinary, multi-laboratory teams of experts focused on solving a single challenge
  - Greatly enhanced collaboration and synergy
  - Spans basic to applied research
- Sigma Team for Minor Actinide Separations (americium, curium) **Started in FY-09**
- Sigma Team for Off-Gas Capture and Immobilization (Iodine, krypton, tritium and carbon-14) **Started in FY-10**
- To date, results have been encouraging, but far too early to claim success

Los Alamos NATIONAL LABORATORY EST.1943
OAK RIDGE National Laboratory
Pacific Northwest NATIONAL LABORATORY
INL Idaho National Laborat
Argonne NATIONAL LABORATORY
Actinide Science at WSU
SRNL
Sandia National Laboratories

Encouraging Innovation

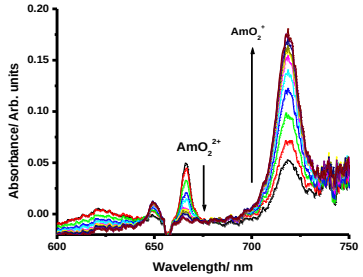
- **Competition for "transformational" fuel recycle approaches via national laboratory white paper call**
  - End of FY-09, issued call to national laboratories
  - Selected 5 innovative white papers for funding in FY-10
- **Competition for innovative alternative waste forms**
  - Funded 6 white papers from national laboratories
  - Alternative waste form calls geared toward meeting Grand Challenges
- **Fundamental science tools and methods development**
  - Funded a number of white paper proposals to develop new tools and methods for understanding separation processes at a fundamental level
- **Significant investment made in fostering innovation**
  - Peer review of FY-10 results and new FY-11 proposals in July 2010

Research areas

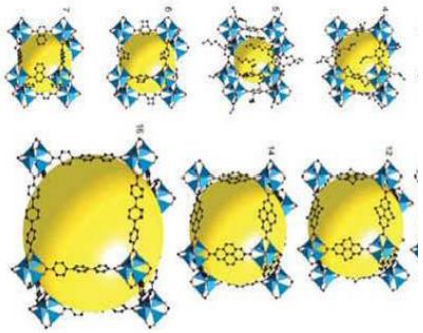
- **Continue work on evolutionary technology development with new emphasis on understanding not only HOW it works, but WHY it works**
  - **Aqueous separation methods**
    - *Thermodynamics and kinetics*
    - *Radiation chemistry*
    - *Solvent degradation*
    - *On-line process monitoring and transformational sampling methods*
  - **Pyrochemical separation methods**
    - *Uranium and TRU recovery and mass balances*
    - *Mechanisms for TRU and fission product drawdown from salt*
    - *Enhanced uranium and TRU product separation/recovery from salt*
    - *Fundamental actinide properties in molten chloride salt*
    - *On-line process monitoring*

Research areas (continued)

- **Sigma Team for Minor Actinide Separation**
  - Separation of americium based on higher oxidation states
  - Single-step Actinide separation from Lanthanides using solvent extraction
  - Extraction chromatography
  - Separations based on solubility in alkaline solutions

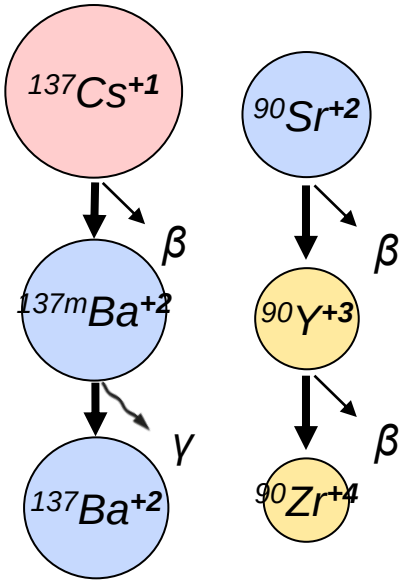


- **Sigma Team for Off-gas Capture and Immobilization**
  - Understand mechanisms and capacity of silver zeolites
  - Alternative Iodine sorbents and waste forms
  - Krypton capture and possible separation from xenon
  - Krypton waste forms as alternative to compressed gas storage
  - Develop understanding of mass balance for pyroprocessing off-gas



Research areas (continued)

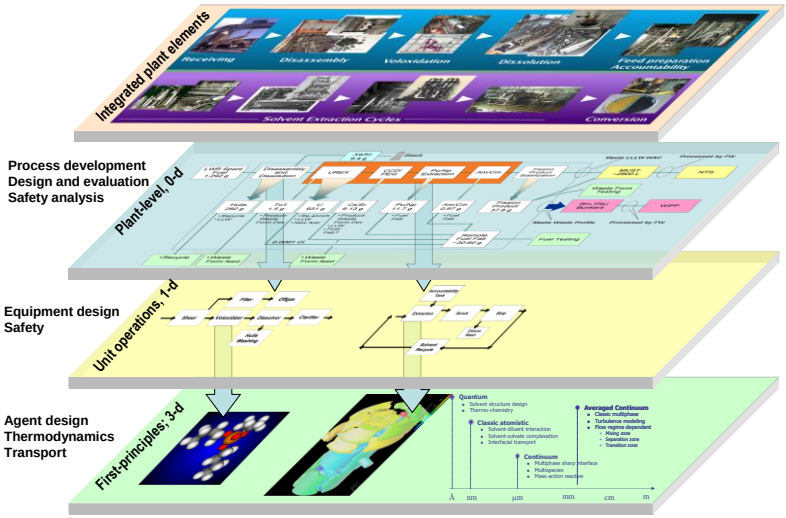
- **Advanced Waste Forms**
  - Glass-ceramics
  - Cermet
  - Epsilon metal phase
  - Pyrochemical waste forms
  - Zirconium recycle
- **Waste Form Characterization**
  - Metal waste form behavior over geologic time scales
  - Oxide waste form behavior over geologic time scales
- **Fundamental Waste Form Science**
  - Continuum constitutive equations
  - Atomistic data/models of waste form structure and dynamics



U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Example modeling and simulation needs for separation technologies

- Models are necessary to help understand fundamental mechanisms and create a predictive capability
- Modeling can reduce the number of (costly) experiments that must be performed
  - Need fundamental phenomenological models
  - Need unit operation models of separation processes
  - Need dynamic process models of separation processes
  - Need balance of plant support models (acid recycle, water balance, etc)
- Some of these models are intended to be lower tier models that will feed into and support higher tier modeling efforts



Additional R&D areas

- **The current separations and waste form programs focus research activities primarily on the "full recycle" option**
- **The "modified open" fuel cycle is a new concept that will require innovative separations, and waste form concepts**
  - Investigate simplified processing methods that do not require full chemical processing and allow greater utilization of existing resources
  - Opportunities may include volatility approaches, physical separations, melt refining, and advanced approaches (supercritical fluids, ionic liquids, etc.)
- **As new fuels and/or fuel cycle options are developed, corresponding separation methods and waste forms must be developed**
  - Need to take a system wide integrated view – developing new fuels with recycle (separations) and waste forms in mind
  - Expand research into new fuel cycles as needed
    - *e.g. thorium, HTGR (TRISO), molten salt, etc*

Summary

- The U.S. FCR&D Separations and Waste Form program is actively pursuing technical options for closing the nuclear fuel cycle
- Program emphasis has shifted from near-term implementation of existing technology (GNEP) to a longer-term R&D effort looking at a broad set of technologies
- Approach is to closely couple theory, experimentation and simulation (goal-driven, science-based approach) to develop better understanding of underlying chemical/physical properties that drive separation processes and waste form behavior
- R&D program includes investment in both “evolutionary” and “revolutionary” technologies
- Alternative fuel cycle approaches are being evaluated, that increase resource utilization and provide additional options for waste management